Analysis of Wall and Invert Systems Report

EXECUTIVE SUMMARY

Introduction

The Analysis of Wall and Invert Systems Report was completed to identify and recommend feasible wall and invert construction alternatives for use in the Reno Railroad Corridor. The walls and inverts recommended in this report are required to function above and below the groundwater table, support buildings, parking lots, the shoofly alignment (a temporary rail alignment required during construction), and work in conjunction with the bridge abutments. Determination of feasibility was accomplished through an analysis of each proposed system.

The proposed wall and invert systems for the depressed rail alignment are summarized below:

1. Slurry-Diaphragm Walls (Walls Only)

   Slurry-Diaphragm walls comprise top-down constructed continuous wall panels consisting of steel reinforced cast-in-place concrete, precast concrete panels or sheet piles placed within an excavated trench temporarily filled with slurry. The slurry, a mixture of bentonite (sodium montmorillonite) and water, is used to prevent caving and water intrusion as the excavation for the wall panel proceeds downward from the ground surface. The excavated trench for a typical wall panel is generally 2 feet to 3 feet in width and 8 feet to 24 feet in length. In appropriate conditions, a slurry trench panel can be excavated to depths well in excess of 100 feet. The panels are excavated such that every other panel is filled with slurry progressively. During the next phase of excavation, the alternate panels are completed and so joined laterally with the existing panels to create a uniform reinforced concrete wall.

2. Jet Grouting (Walls and Inverts)

   Jet grouting is a top-down soil treatment used to create in-situ, cemented soil formations. The method uses pressurized fluids to segregate and remove some of the soil particles and replace them and blend them with a soil/cement mixture that can provide high strength and low permeability.

   Rotating high-pressure fluid jets, activated while withdrawing grouting rods from a predrilled boring, form cylindrical columns. Jet grouted walls and inverts can be constructed by overlapping these cylindrical columns.

3. Permeation Grouting (Walls and Inverts)

   Permeation grouting is the injection of cement or chemical grouts into predominately granular soils from the original ground surface. Grouts may include resins, silicates/emulsions, bentonite cement, and cement although most work is done with cement-based grout. The grout is injected into the soil through pipes that have been strategically placed to define the zone of soil to be treated.

4. Secant/Tangent Piles (Walls Only)

   Secant and tangent pile walls consist of a top-down constructed continuous line of drilled piers extending below the excavation subgrade. Overlapping or cutting into adjacent drilled shafts defines secant pile wall installation. Tangent pile walls consist of shafts butting up to adjacent shafts, or shafts separated by a small distance with the gap filled by a smaller diameter drilled pier located behind the primary row of shafts. Shafts are excavated by either wet or dry drilling techniques.

5. Cast-In-Place Concrete Slab

   Cast-In-Place concrete slabs are constructed on a prepared surface with traditional construction methods. In below groundwater conditions, the subsurface is sealed with tremied concrete (a technique for depositing and consolidating concrete underwater from the bottom upward) to provide a solid working surface capable of supporting construction equipment, materials and workers. Upon completion of the working surface, the work area is dewatered and steel reinforcement mats are constructed. Forms are placed for pours of manageable quantity to maintain workability and concrete bond quality.

6. Cantilever Walls (Walls Only)

   Cantilever walls are cast-in-place reinforced concrete structures. These wall systems consist of constructing a wall stem and footing in stages from the bottom up. Cantilever wall systems are common structures designed to resist overturning, sliding and sinking.

7. Mechanically Stabilized Earth Walls (Walls Only)

   The mechanically stabilized earth (MSE) wall system consists of multiple layers of horizontal inclusions (reinforcing elements). Inclusions consist of continuous or semi-continuous layers of geotextile, geogrid, or welded wire fabric. Select compacted backfill is placed in alternately horizontal layers from the bottom of the wall upward. Typically, this type of wall is completed with some type of facing system.

8. Micropile Walls (Walls Only)

   Micropiles are small-diameter grouted in-place piles constructed with some form of steel reinforcement installed from the original ground surface. Micropile drilled shafts are accomplished with a variety of overburden drilling techniques and are typically up to 8 inches in diameter and drilled to a depth of approximately 1.5 times the wall height.

9. Soil Nail Walls (Walls Only)

   Installed through the face of an excavation at an inclination of approximately 15 degrees (downward from horizontal), soil nail walls consist of closely spaced steel bar reinforcements (5-foot centers). The soil nails reinforce the in-situ soil mass and allow for top-down construction of an excavation. The excavation is typically advanced in 5-foot lifts with soil nails installed as the soil in front of the finished face is removed. The nails increase the shear strength of the overall soil mass and limit displacement during and after excavation. Shotcrete is applied to the face to provide local resistance to raveling. This technique is not suitable for construction below the groundwater table.

10. Soldier Piles and Lagging (Walls Only)

    Soldier pile and lagging systems are typically used for temporary bracing of large excavations. These retention systems consist of vertical, steel rolled "H" sections installed every 5 feet to 10 feet along the perimeter of an excavation with horizontal timber lagging spanning the distance between the piles. Soldier piles and lagging is a top-down technique requiring excavation to complete the wall construction and can only be used above the groundwater table.

11. Stresswall System (Walls Only)

    Stresswall, an example of a proprietary wall system (many others are available), is comprised of two precast concrete elements: 1) louvered columns supported on concrete filled shafts and 2) wall panels set between the precast columns and held in place by soil pressure. The system is very similar to soldier pile and lagging with top down construction, requiring excavation to install lagging.

12. Ground Freezing (Walls and Inverts)

    Freezing (refrigeration) is used to achieve temporary ground stability or control of groundwater in soft soils or excavations below the groundwater table, or to achieve continuous stability in permafrost regions where thawing must be prevented. Ground freezing methods are temporarily utilized to aid in the construction of permanent wall or invert systems.

13. Sheetpiles (Walls Only)

    Sheetpile walls consist of interlocking vertical members of timber, concrete, or steel. These vertical members are typically driven or vibrated from the original ground surface to a specified depth.

    In addition, sheetpiling may be used in conjunction with diaphragm construction by placing the sheets into the slurry mix. This combined use decreases permeability and enhances the water barrier features of diaphragm construction.

14. Deep Mixing (Walls and Inverts)

    Deep mixing is top-down soil treatment involving in-situ mechanical mixing of soil with cementitious materials (slurry or dry powder reagent binder) using a hollow stem mix tool. Sets of 1 to 3 shafts with mixing tools, up to 8-feet in diameter, are used to mix soft and loose soils to depths of 100 feet. The hollow stem is used as a conduit to pump grout and mix the soil as the tool advances and/or withdraws, resulting in a column of treated soil.

Analysis: Each of the previous wall and invert systems was analyzed for functional performance, cost considerations, environmental impacts, and production rates. The specific criteria used in the analysis of each wall system are listed below:

1. Applicability to Soil Conditions

   Analysis to determine if the systems were feasible for the specific soil conditions of the City of Reno vicinity. Wall or invert systems that can be constructed with reasonable ease in boulder/cobble conditions received high marks in this analysis category.

2. Stability of Wall Construction

   Special geotechnical consideration is required for two of the proposed wall construction techniques, namely slurry-diaphragm and secant-tangent pile walls. Excavations required for slurry-diaphragm and secant-tangent pile walls are typically held open using bentonite slurry (a mixture of native soil, bentonite, and water) until they can be backfilled with structural concrete. The outward pressure provided by the slurry, on the sides of the excavation, resists the lateral forces that cause caving. However, a major concern of applying this technique to the excavation in the Reno Railroad Corridor is the stability of this system when employed adjacent to live heavy rail.

   During the construction of this proposed trench system, Union Pacific Railroad (UPRR) will be operating live rail. This operation may be as near as 16 feet from the slurry filled excavation. Examination of this operation was required to determine the susceptibility of the trench to caving and the magnitude of vertical displacements under the UPRR track. Only those wall techniques that provide for stable construction adjacent to live heavy rail operations were considered for recommendation.

3. Groundwater Control

   The exorbitant costs associated with pumping and treating large volumes of water, combined with the adverse environmental impacts associated with mitigation of water infiltration, favor a top down method of construction.

   Additionally, the final trench configuration must provide a groundwater barrier that resists seepage greater than the quantity of water that can be evaporated. The evaporation rate used was an annual average of 9.0×10^{-2} gal/day per square foot of exposed area (based on historic data). For applications below the groundwater table, only wall systems that can be constructed with coefficients of permeability less than 1×10^{-6} cm/sec were given consideration.

4. Abutment-Related Issues (Wall Systems Only)

   The ability of the wall system to function as a bridge abutment without major modifications or severe cost or schedule implications. The wall systems requiring fewer modifications to support bridge structures were advanced in the selection process.

5. Duration of Construction

   Estimated production rates of each system was tested against a targeted construction timeframe established by the City of Reno. Those systems constructible within the targeted timeframe were selected for further consideration.

6. Traffic and Noise Impact

   Examination of the construction process and the equipment used was necessary to determine the magnitude of traffic and noise impacts to project constituents. The preference for a wall or invert system was inversely proportional to its negative effect on the adjacent community through construction impacts on traffic and noise.

7. Right Of Way Impact (Wall Systems Only)

   Analysis was conducted to determine the compatibility of each wall system with the proposed easements outlined in the *Draft Reno Railroad Corridor Environmental Impact Statement*. Only wall systems with easement and right-of-way requirements that were within the bounds of the *Draft Reno Railroad Corridor Environmental Impact Statement* were recommended for construction.

   Since the invert to the trench is confined within the wall systems, no right-of-way consideration was necessary for these techniques.

8. Aesthetics (Wall Systems Only)

   Examination of the aesthetic features of each wall system and the possible variations to cost and production associated with these treatments. In the consideration of recommended wall systems, those that were the most aesthetically pleasing and did not require facing elements were given more weight than those requiring aesthetic treatments.

   Since the invert will be covered by trackage and a maintenance road, limited portions may be visible from the trench top. With this limited exposure, aesthetics were not considered for invert systems.

9. Conceptual Calculations

   Once the design feasibility of each system was determined through completion of preliminary engineering, a typical trench section was designed for the most probable location in the proposed project.

10. Cost

    Through examination of the preliminary engineering and collaboration with construction experts for each structural system, an approximate cost was established for each technique (based on a per-square-foot value).

11. History of Successful Application

Proof of successful application was accomplished through case history documentation from construction experts. Only wall and invert systems with a history of success were considered for final recommendations.

12. Application

Regions of applicability within the project limits were identified. Accompanying the regions of applicability, analysis of the installation procedures, availability of equipment and materials, single-track railroad operations of the central shoofly, and functional performance was completed. Consideration for a particular wall type was proportional to its project applicability.

The analysis was conducted through examination of existing research, collaboration with technical experts, and application of experience and engineering judgement.

Results (Wall Systems)

This report discusses the advantages, disadvantages, and applicability of thirteen independent wall systems. With each discussion topic, these wall options were challenged against project criterion that determined their applicability to the Reno Railroad Corridor project. With the large number of proposed options for the wall systems in this project, it was necessary to develop screening criteria to narrow these options to the most practical, feasible and economic wall type. A summary of each proposed wall method, segregated by region of applicability, is presented in the chart below.

Wall Type	Project Criterion									
	Applicability to Soil Conditions	Groundwater Control	Abutment Related Issues	Duration of Construction	Traffic and Noise Impact	Right Of Way Impact	Aesthetics	Cost	History of Successful Application	Application
Global Methods (Zone 1 or Zone 2)										
Slurry-Diaphragm Walls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Jet Grouting	✓	✓	X	✓	✓	✓	X	✓	✓	✓
Permeation Grouting	X	✓	X	X	✓	✓	X	X	X	X
Secant/Tangent Piles	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Above Groundwater Methods (Zone 1)										
Cantilever Walls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mechanically Stabilized Earth Walls	✓	X	✓	✓	✓	✓	✓	✓	✓	✓
Micropile Walls	✓	X	✓	X	✓	✓	✓	X	✓	✓
Soil Nail Walls	✓	X	X	✓	✓	✓	✓	✓	✓	✓
Soldier Piles and Lagging	✓	X	✓	X	✓	✓	✓	✓	✓	✓
Stresswall System	✓	X	✓	X	✓	✓	✓	✓	✓	✓
Inapplicable Methods										
Ground Freezing	X	X	✓	✓	✓	✓	✓	✓	✓	✓
Sheetpiling	X	✓	✓	✓	X	✓	✓	✓	✓	X
Deep Mixing	X	✓	✓	✓	✓	✓	✓	✓	✓	X

Figure 1 Screening Criteria

In the chart above, each wall system is listed against the selection criteria and marked with a check (✓) for criteria that are satisfied and an "**X**" for criteria that are not satisfied.

Three wall types, examined for application above the groundwater table only, satified all selection criteria, 1) cantilever walls, 2) mechanically stabilized earth walls, and 3) soil nail walls. Below the groundwater table, two wall types satisfied all selection criteria, slurry-diaphragm walls and secant/tangent pile walls. The final recommendations test these wall types against costs and production rates.

The following production rates are based on the preliminary estimates obtained from specialty contractors and/or field experts in each of the construction methods. For regions above the groundwater table, a total of 180,000 ft^2 of wall is required. The regions below the groundwater table require 260,000 ft^2. Using double shifts at two headings, construction durations were developed.

Wall Type	Rate (ft^2/shift)	Remarks
Global Methods (Zone 1 or Zone 2)		
Slurry-Diaphragm Walls	800[1]	
Jet Grouting	135[2]	Based on 2 row of columns
Permeation Grouting	189[2]	Based on 2 row of columns
Secant/Tangent Piles	190[3]	
bove Groundwater Methods (Zone 1)		
Cantilever Walls	1,067	
Mechanically Stabilized Earth Walls	1,800[4]	
Micropile Walls	58[5]	
Soil Nail Walls	1,000[5]	May be increased 2 or 3 times depending on access and schedule
Soldier Piles and Lagging	215[3]	
Stresswall System	215[4]	

Figure 2 Production Rates

[1] Michael Pagano, TREVI ICOS Corporation, Morgan Hill, CA
[2] Mark Doehring, Kleinfelder, Reno, NV
[3] William Fishetti, PE, Malcolm Drilling Company, Vista, CA
[4] John Babcock, Transwall Earth Retaining System, Ogden, UT
[5] Donald A. Bruce, PhD, C. Eng, FICE, GEOSYSTEMS LP, Venetia, PA

Through collaboration with the specialty contractors, field experts, and published construction cost data from Caltrans, estimated costs were established. These wall costs, neglect the secondary lateral support systems (struts or grouted ground anchors) as required for each wall type. For final estimate purposes, the appropriate secondary support system must be selected and additional costs must be added.

Wall Type	Wall Cost	Remarks
Global Methods (Zone 1 or Zone 2)		
Slurry-Diaphragm Walls[1]	$70/ft²	
Jet Grouting[2]	$80/ft²	based on 2 rows of columns
Permeation Grouting[2]	$71/ft²	based on 2 rows of columns
Secant/Tangent Piles[3]	$107/ft²	
Above Groundwater Methods (Zone 1)		
Cantilever Walls[4]	$35/ft²	
Mechanically Stabilized Earth Walls[4]	$42/ft²	
Micropile Walls[5]	$67/ft²	
Soil Nail Walls[5]	$25/ft²	
Soldier Piles and Lagging[6]	$87/ft²	Included required anchors
Stresswall System[7]	$45/ft²	

Figure 3 Construction Costs

[1] Michael A. Pagano, P.E., TREVI ICOS Corporation, Morgan Hill, CA
[2] Donald A. Bruce, PhD, C. Eng, FICE, GEOSYSTEM, LP, Venetia, CA
[3] William Fishetti, PE, Malcolm Drilling Company, Vista, CA
[4] Caltrans Historic Data 1996 through 1999
[5] Ron Chapman, Schnabel Foundation Company, Walnut Creek, CA
[6] Caltrans Historic Data 1996 through 1999
[7] John Babcock, Transwall Earth Retaining System, Ogden, UT

Results (Invert)

This report discusses the advantages, disadvantages, and applicability of three independent invert systems. With each discussion topic, these invert options were challenged against project criterion that determined their applicability to the Reno Railroad Corridor project. With the diverse options for the proposed invert system in this project, it was necessary to develop screening criteria to narrow these options to the most practical, feasible and economic invert type. A summary of each proposed invert method is presented in the chart below.

Invert Type	Project Criterion						
	Applicability to Soil Conditions	Groundwater Control	Duration of Construction	Traffic and Noise Impact	Cost	History of Successful Application	Application
Global Methods (Zone 1 or Zone 2)							
Jet Grouting	✓	✓	✓	✓	✓	✓	✓
Permeation Grouting	X	✓	X	✓	✓	X	X
Cast-In-Place Concrete Slab	✓	✓	✓	✓	✓	✓	✓

Figure 4 Screening Criteria

In the chart above, each invert system is listed against the selection criteria and marked with a check (✓) for criteria that are satisfied and an "X" for criteria that are not satisfied.

Only two invert type satified all selection criteria, jet grouting and cast-in-place concrete slab. However, as noted in the report, these methods have a symbiotic relationship and function better as a joint application. Since the combination of these methods is the only viable option examined in this report, further examination of production rates and costs is not necessary for recommendation.

Conclusions and Recommendations

WALL SYSTEMS

Conclusions: The findings, summarized above, are refined by eliminating costly or slower constructed selections. Each region was examined independently. Those eliminated from contention in regions above the groundwater table due to production rates are 1) soldier piles and lagging, 2) Stresswalls and 3) micropiles. The remaining above groundwater applications (cantilever walls, mechanically stabilized earth, and soil nailing[not applicable at bridge abutments]) are all within acceptable limits with regard to cost and production rates.

Below the groundwater table, only two choices fulfilled the selection criteria, slurry-diaphragm walls and secant/tangent piles. Based on the best production rates and most economical solution, slurry-diaphragm walls are the preferred alternative.

Recommendations: Based on production rates, costs, and functional ability, the wall systems recommended to be most suitable for use above the groundwater table are: 1) cantilever walls, 2) mechanically stabilized earth and 3) soil nailing[not applicable at bridge abutments].

The wall system recommended to be most suitable for use below the groundwater table is slurry-diaphragm walls.

INVERT SYSTEMS

Conclusions: The findings, summarized above, illustrate a clear recommendation for an trench invert system. The preferred system for the Reno Railroad Corridor is a combination of two techniques, name jet grouting to construct a temporary groundwater barrier in preparation for a permanent invert system, a cast-in-place concrete slab. In addition, it was found that permeation grouting, while an adequate technique for creating a groundwater barrier serves better as a remediation method for localized seapage.

Recommendations: Based on production rates, costs, and functional ability, the invert system recommended to be most suitable for is jet grouting to temporarily seal the trench for the installation of a permanent solution, namely cast-in-place slab.